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13. ABSTRACT (Maximum 200 words)
The purpose of this work was to determine how to obtain the maximum reinforcement from thermotropic liquid crystalline polymers (TLCPs) when blended with other thermoplastics to produce light weight, wholly thermoplastic composites. Towards this goal, the research first focused on the spinning of thermoplastic/TLCP composite strands and fibers using a novel dual extrusion technique developed in our laboratory. It was found that the high degree of extensional deformation achieved in spinning and the ability to utilize the supercooling behavior of the TLCPs allowed a wide variety of thermoplastic/TLCP composite systems to be produced with properties matching or exceeding theoretical expectations. The strands and fibers generated in the spinning step were then subjected to a variety of post-processing techniques. This was done to expand the processing options available while retaining the high mechanical properties of the pregenerated TLCP fibrils. These post-processing techniques included: 1) manufacturing and consolidating woven thermoplastic/TLCP composite preforms, 2) injection molding of pregenerated microcomposites, and 3) rapid prototyping. Each of these techniques was shown to produce composites with higher mechanical properties than those of the neat matrix resins.

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THE PROCESSING OF IN SITU COMPOSITES AND MICROCOMPOSITES BASED ON THERMOTROPIC LIQUID CRYSTALLINE POLYMERS AND THERMOPLASTICS

FINAL REPORT

DONALD G. BAIRD

May 28, 1998

U.S. ARMY RESEARCH OFFICE

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A. Statement of the Problem Studied

The purpose of this work was to determine how to obtain the maximum reinforcement from thermotropic liquid crystalline polymers (TLCPs) when blended with other thermoplastics to produce light weight, wholly thermoplastic composites. Towards this goal, the research first focused on the spinning of thermoplastic/TLCP composite strands and fibers using a novel dual extrusion technique developed in our laboratory. It was found that the high degree of extensional deformation achieved in spinning and the ability to utilize the supercooling behavior of the TLCPs allowed a wide variety of thermoplastic/TLCP composite systems to be produced with properties matching or exceeding theoretical expectations. The strands and fibers generated in the spinning step were then subjected to a variety of post-processing techniques. This was done to expand the processing options available while retaining the high mechanical properties of the pregenerated TLCP fibrils. These post-processing techniques included: 1) manufacturing and consolidating woven thermoplastic/TLCP composite preforms, 2) injection molding of pregenerated microcomposites, and 3) rapid prototyping. Each of these techniques was shown to produce composites with higher mechanical properties than those of the neat matrix resins.

Further details of the results of this research are provided below. First, the properties of the composite strands and fibers are discussed. This is followed by the various post-processing schemes used, covering woven composite preforms, injection molding, and rapid prototyping.

B. Summary of Results

Thermoplastic/TLCP Composite Strands and Fibers

A patented dual extruder fiber spinning process was used to form thermoplastic/TLCP composite fibers and strands. The thermoplastics used included polypropylene (PP), poly(ethylene terephthalate) (PET), nylon 11, and polyphenylene sulfide (PPS). The TLCPs used were primarily Vectra A950 (VA), Vectra B950 (VB), HX8000, and HX1000, although a limited amount of work was performed using HX6000 and HX7000 as well. The specific thermoplastic/TLCP combination used depended on the supercooling behavior of the TLCP, with the some of the combinations investigated and the draw ratios produced shown in Table 1. In particular, the TLCP had to be able to be cooled below the degradation temperature of the matrix while still remaining deformable/spinnable. This criterion was necessary because in the dual extruder processing scheme the TLCP is cooled below its normal processing temperature before being introduced into the matrix, allowing thermoplastic/TLCP combinations to be made without degradation of the thermoplastic resin.

Table 1: Examples of Compositions Investigated and the Draw Ratios Achieved

Combination	Composition (wt/wt%)	Highest Draw Ratio	Tensile Modulus (GPa)
Nylon 11/HX8000	87/13	130	9
Nylon 11/HX8000	78/22	150	14.5
Nylon 11/HX8000	65/35	140	21.5
PET/HX1000	50/50	108	26.5
PET/HX6000/HX8000	50/25/25	45	28
PP/Vectra B950	50/50	220	44
PP/Vectra A950	28/72	185	15
PPS/Vectra B950	50/50	130	55

One result of the work on spinning composite strands is it established that strands and fibers containing a wide variety of thermoplastic/TLCP combinations could be produced which could not be made without utilizing the supercooling behavior of the TLCPs. Progressing through the examples in Table 1, HX8000 has to be taken to at least 290°C in order to be melt processed, while nylon 11 can not be taken above 260 to 270°C before considerable degradation is encountered. HX1000 must be processed at at least 310°C and HX6000/HX8000 has to be taken to temperatures of 350°C, both well above the maximum processing temperature of 300°C for PET. Vectra A950 must be heated to at least 320°C to remove all high melting crystallites, at least 30°C above the maximum temperature PP can be exposed to. However, because the dual extruder system cools the TLCP melt before introducing it into the matrix, it was possible to produce composite strands with high draw ratios and mechanical properties with no appreciable degradation to the matrix. Therefore, the broad selection of polymers used has shown the utility of the dual extruder process in combining TLCPs and matrices with nonoverlapping processing temperatures.

The effect of fiber draw ratio on the tensile modulus was investigated for PP/VB at a composition of 50/50 weight percent (wt%) for draw ratios up to 220. Consistently, the tensile moduli of the composites were found to match or exceed the rule of mixtures predictions. For example, PP/VB fibers exhibited tensile moduli greater than 30 GPa for draw ratios greater than 40. This is in excess of the rule of mixtures predictions, using an as-spun modulus of 75 GPa for VB and a modulus of 1.01 GPa for PP. This synergistic effect implies that the TLCP fibrils in the in situ fibers have higher tensile properties than

can be achieved with neat Vectra B950. In particular, it was speculated that the PP served to insulate the VB fibrils, allowing them to be drawn more before solidification and thereby achieve a higher degree of molecular orientation.

Another example of the exceptional properties which can be generated with the dual extruder system is that of the nylon 11/HX8000 fibers. Composite strands were spun with loadings of 13, 22, and 35 wt% HX8000. For neat HX8000, it has been determined that a maximum tensile modulus of approximately 47 GPa is reached for draw ratios over 50. However, the composite strand properties were greater than predicted based on this modulus. Using the rule of mixtures, the modulus of the TLCP phase was calculated to be as high as 70 to 80 GPa, approximately 70% greater than that of the neat HX8000 fibers. In accounting for this difference in properties, it was stated that the TLCP fibrils in the composite strands had higher degrees of molecular orientation than the neat TLCP fibers. Based on these experimental results, it is clear that the dual extruder process allows consistently high levels of reinforcement to be attained, with the composite strand moduli often exceeding theoretical expectations.

It was also determined that some composite strands could be compression molded while retaining their mechanical properties. Consolidating strands of PET/HX1000 (50/50 wt%) into uniaxial composites at a temperature of 260°C resulted in little loss in properties. The initial test strands had a modulus of 25.5 GPa. After consolidation and further exposure to 260°C for up to one hour, the uniaxial composites had tensile moduli of 20 to 23 GPa. Morphological examinations of the strands before and after consolidation showed the same fibrillar structure, confirming that the TLCP fibrils had withstood the high temperature and long exposure time and had not relaxed into droplets.

This result matches earlier work with PP/HX1000 and other composite strands, demonstrating that for some materials, it is possible to consolidate without causing a substantial reduction in stiffness.

Woven Thermoplastic/TLCP Composite Preforms

A comprehensive study of woven preforms composed of PP and VB was undertaken, examining the effects of TLCP loading level and fabric layer distribution on the mechanical properties as well as the formability of these materials. It was found that as the TLCP loading level was increased, the modulus of the composites greatly exceeded that of neat PP. Specifically, even at a loading level of only 9.84 wt% VB, the tensile modulus of the consolidated preforms was 3.87 GPa, versus 1.01 GPa for neat PP. Meanwhile, when the loading level of 31.5 wt%, the consolidated preforms were found to have a tensile modulus of 10.3 GPa, a ten-fold increase over that of neat PP. Note that this specimen was predicted to have a modulus of 12.0 GPa based on composite theory, so the final composite retained over 85% of the original strand modulus.

It was also determined that the placement of preform layers could significantly affect flexural properties. At a loading of roughly 9.5 wt% VB, it was found that the flexural modulus could be increased from 3.22 GPa to 5.23 GPa by changing the distribution of preform layers from being evenly spaced through the thickness of the composite to selectively placing the layers near the composite surfaces. The reason for this behavior was because the reinforcing TLCP fibrils were located where the greatest tension / compression occurred during flexural loading.

To evaluate the formability of the PP/VB (~ 80/20 wt%) composites produced from consolidated woven preforms, the tensile elongation at break was determined as a function of temperature. It was found that for an orthotropic composite with an even distribution of four fabric layers across the composite cross section, it was possible to reach a percent elongation of 15% when taken to a temperature of 250°C. It is not possible for composites reinforced with conventional fibers such as fiberglass or carbon to reach such high levels of elongation. Having established that the composites could be stretched, tests were performed proving that they could be thermoformed. Thus, TLCP reinforced preforms can be used to produce composite sheets without a significant loss in mechanical properties, which can then be used in subsequent forming steps to produce wholly thermoplastic composite parts.

Injection Molding of Pregenerated Microcomposites

The pregenerated microcomposite processing scheme involved two processing steps. First, fibers were spun using the dual extruder process. These composite strands were then chopped, mixed with additional injection molding grade matrix pellets and injection molded using temperatures well below the processing temperature of the TLCP. This was done in an attempt to retain the properties of the pregenerated TLCP fibrils in the final injection molded part while distributing reinforcement in both the machine and transverse directions. This would overcome the problem of anisotropy that in situ injection molded composites are known for. However, in order to obtain the maximum mechanical properties in these composites, it was necessary to study the influence of various

processing variables.

One processing variable which was studied was the influence of resin viscosity on mechancial properties. This was done by injection molding two sets of composites containing 20 wt% HX1000 fibrils using a film-gated plaque mold. The first set was made from PT 7067/HX1000 (80/20 wt%) composite strands, with PT 7067 being a blow molding grade of PET manufactured by DuPont. The second set was made from chopped PT 7067/HX1000 (50/50 wt%) strands, which were diluted to a loading of 20 wt% HX1000 by dry blending the chopped strands with Rynite, an experimental, low viscosity grade of PET made by DuPont. Examining machine direction tensile properties, the PT 7067/HX1000/Rynite (20/20/60 wt%) pregenerated microcomposites had a machine direction tensile modulus of 4.586 GPa, versus just 3.106 GPa for the PT 7067/HX1000 (80/20 wt%) composites. Similar results were seen in flexural modulus as well. Hence, the results clearly demonstrated that better mechanical properties were obtained by diluting with a low viscosity resin, possibly because the low viscosity resin helped reduce the damage the TLCP fibrils sustained as they passed through the injection molding process.

In making pregenerated microcomposites using PET as the matrix resin, it was determined that two advantages were obtained by diluting with an Celenex 1600A, an injection molding grade of poly(butylene terephthalate) manufactured by Hoechst-Celanese, rather than the injection molding grade PET Rynite. Specifically, because Rynite had a melting temperature of 257°C versus 228°C for Celenex 1600A, it was possible to lower some of the injection molding zone temperatures, thereby minimizing the temperatures to which the HX1000 fibrils were exposed. Also, it was found that by

diluting with PBT, a homogeneous, thoroughly mixed melt was formed earlier in barrel of the injection molder. This meant that the PBT was able to wet the HX1000 fibrils earlier in the injection molding screw, leading to better mechanical properties. For example, composites composed of PT 7067/HX1000/Rynite (30/30/40 wt%) had a machine direction flexural strength of 79.15 MPa while those with a composition of PT 7067/HX1000/Celenex 1600A had a flexural strength of 95.74 MPa. Similar increases in tensile strength, percent elongation, and tensile toughness were also observed, while tensile and flexural moduli remained roughly constant. Of particular interest is Celenex 1600A which had lower tensile and flexural strengths than Rynite (45.81 MPa vs. 49.40 MPa and 60.42 MPa vs. 69.04 MPa, respectively). This indicates that the improvements in strength were due to better reinforcement from the HX1000 fibrils, which were probably damaged less when PBT was used as the diluting resin.

Because pregenerated microcomposites have the potential to compete with glass fiber reinforced thermoplastics, it was important to compare mechanical properties of these two systems. When this comparison was made, generally it was found that the pregenerated microcomposites did not possessed properties as high as those of glass filled thermoplastics. At a loading of 30 wt% HX1000 a machine direction tensile modulus of 5.8 GPa was obtained, versus 9.2 GPa when 30 wt% glass fiber was used. Additionally, in areas such as strength, percent elongation, and tensile toughness, the glass filled systems tend to outperform pregenerated microcomposites.

Still, the potential to be competitive with glass fiber reinforcement exists. Theoretically, a planar isotropic PET/HX1000 (70/30 wt%) composite should possess a modulus of 7.26 GPa, versus 6.80 GPa for a planar isotropic sample of PET reinforced

with 30 wt% glass fiber. This shows that if the losses in mechanical properties can be minimized, the pregenerated microcomposites should be as stiff or stiffer than glass filled polymers. Also, it has been determined that because of the smaller size of the TLCP fibrils, the pregenerated microcomposites have smoother surfaces than glass filled resins. Heat distortion properties of pregenerated microcomposites are competitive as well, as evidenced in dynamic mechanical thermal analysis of PET/HX1000 based pregenerated microcomposites, where the storage modulus closely matched that of glass filled PET at temperatures up to the glass transition temperature of HX1000 at 160°C. Thus, if the mechanical properties of the composite strands can be retained in the injection molded pregenerated microcomposites, the potential exists to produce light weight, wholly thermoplastic composites which are as stiff as glass filled thermoplastics, have high heat distortion properties, and possess smoother surfaces.

In addition to conventional injection molding, pregenerated microcomposites were coinjection molded. This was done because the coinjection molding process: 1) avoided plasticating the TLCP reinforcement in the injection molder barrel and 2) selectively placed the reinforcement on the surface of the plaque. Comparing the coinjection molded composites to conventionally injection molded composites showed that coinjection molding did not produce higher tensile properties, but the flexural moduli did increase. The conventionally injection molded composites had a machine direction flexural modulus of 4.885 GPa and a transverse direction modulus of 2.965 GPa, while coinjection molding produced a composite with a machine direction flexural modulus of 6.708 GPa and a transverse direction modulus of 4.144 GPa. This demonstrated that for applications where

it is important to have high flexural stiffness, the coinjection molded composites have better properties.

The properties of the coinjection molded composites were also compared to conventionally injection molded glass filled PET. It was determined that the flexural moduli of the coinjection molded composites matched what was obtained with glass filled PET, but the other mechanical properties were lower. This showed that although selectively placing the reinforcement on the plaque surface did yield composites with high stiffnesses, improvements will need to be made to obtain tensile properties which are competitive with glass filled PET.

In addition to examining the mechanical properties, tests were performed to determine if there was a difference in surface roughness between HX1000 fibril reinforcement and glass fiber reinforcement. Specifically, the HX1000 fibrils had diameters of approximately 2 μm while the glass fibers had diameters of 12 μm, so the smaller fibril diameter could reduce surface roughness. It was demonstrated that although the coinjection molded composites had surfaces with 50 wt% reinforcement, their surfaces were smoother than those of conventionally injection molded PET containing just 30 wt% glass fiber and were only slightly rougher than PET containing 20 wt% fiber. Hence, the smaller diameter of the HX1000 fibrils yielded composites with significantly smoother surfaces at high loading levels.

Another variable which was investigated was the effect of the core material on mechanical properties, with composites possessing cores of either neat Rynite or Rynite 530. The mechanical properties showed that using glass-filled PET as the core material improved both tensile and flexural properties. For example, the machine direction tensile

modulus increased from 3.884 GPa to 7.269 GPa. This result indicates that coinjection molding provides a method to produce a highly filled composite which utilizes both 1) the ability of the pregenerated TLCP fibrils to give smoother surfaces and 2) the ability of the glass fiber to supplement the reinforcing ability of the HX1000 fibrils.

Rapid Prototyping

Fused Deposition Modeling (FDM) is a process by which a prototype part can be generated without going through expensive mold making or machining operations. For polymeric materials FDM consists of extruding a fine filament of polymer melt from a head which is able to move in the x-y plane onto a bed which can move up and down along the z direction. The operation of the head and bed are controlled by a computer in such a way that a three dimensional part can be laid up.

One goal in the work with FDM was to determine if the extrusion head could be fed with a microcomposite material, in this case PP reinforced with Vectra A950 (VA). The potential in this work is that parts could be produced with properties which are more functional. Because the opening in the extrusion head is very small, polymers filled with glass or other reinforcing fiber can not be used. Specifically, because their diameters are typically 10 to 20 microns, aspect ratios of over 100 can not be retained as they pass through the extrusion head. Because TLCP fibrils typically have diameters an order of magnitude smaller, they have the potential to be used in this application where other forms of reinforcement can not be successful.

The PP/TLCP composite strands which were generated for feeding the extrusion head contained pregenerated TLCP fibrils of diameter of about 1 micron and aspect ratios in the range of 30 to 100. Composite samples (actually test strips) were laid up with different types of fiber orientation. The modulus of these parts was similar to that of glass filled PP under injection molding conditions, but the strength was not increased. Hence, it may be possible now to make complex shaped prototypes with properties which will allow them to be tested under operating conditions. This is especially true in the case when the material to be used has the properties of a short glass reinforced composite.

Another point investigated in this work was if lay-down pattern had an effect on final mechanical properties. It was found that the lay-down pattern used in forming the composites did influence the mechanical properties of these composites. In particular, it was determined that the tensile properties of the VA/PP composites increased monotonically with roads laid in the machine direction. Thus, the final mechanical properties of a prototype can be tailored to a specific application by adjusting the lay-down pattern, increasing the functionality of the prototype.

The FDM processing scheme requires strands which have very specific diameters in order to be feed into the machine. Therefore, it was not possible to use strands directly produced from the dual extrusion process. Rather, the strands were re-extruded using a capillary rheometer to form extrudate with the desired dimensions. These could then be used in the rapid prototyping equipment. However, the re-extrusion process needed to be studied to determine its viability and the effect it had on the pregenerated TLCP fibrils, as shown by mechanical testing.

It was determined that long fiber reinforced PP/VA composite monofilaments could be generated via a plunger driven extrusion system. This extrusion system has the potential to be implemented in a FDM rapid prototyping system which can fabricate long fiber reinforced prototypes with tensile properties similar to those of long fiber reinforced monofilaments. The tensile properties of the monofilaments generated using this extrusion system, and potentially those of prototypes fabricated from a similar FDM system, have greater mechanical properties than those of previously fabricated prototypes reinforced with short TLCP fibers.

It was found that the tensile properties of composite monofilaments were less than those of the composite strands, and this was attributed to the thermal and deformation history imposed during post-processing. It was found that the thermal history imposed during consolidation of 20 wt% and 40 wt% Vectra A composite strands at 180°C resulted in approximately a 20% reduction in the tensile moduli of both materials. This reduction in tensile moduli was potentially due to a decrease in orientation of the Vectra A reinforcement as a result of molecular relaxation or as a result of poor strand alignment during consolidation.

It was determined that the deformation history during re-extrusion of the composite strands affected the mechanical properties of the long fiber reinforced monofilaments. It was shown that the capillary L/D, the capillary diameter, and the apparent shear rate in the capillary affected the properties of the composite monofilament when processed at 180°C. It was determined, for the post-processing conditions considered, that smaller diameter capillary dies and lower apparent shear rates resulted in greater tensile properties of the composite monofilament. It was also determined, for the

post-processing conditions studied, that a critical L/D was necessary in order to obtain the optimal mechanical properties in the monofilaments.

C. List of Publications and Technical Reports

The following is a list of manuscripts submitted or published under ARO sponsorship during the duration of grant number DAAH04-94-G-0282. This includes the journal and references for papers which have been published.

Manuscripts Published - 1995

Datta, A. and Baird, D.G.: Compatibilization of Thermoplastic Composites Based on Blends of Polypropylene with two Liquid Crystalline Polymers, *Polymer*, 36, 505-514 (1995).

McLeod, M.A. and Baird, D.G.: Comparison of Properties of Microcomposites and In Situ Composites Based on Poly(ethylene terephthalate) and Thermotropic Liquid Crystalline Polymer, *ANTEC Tech. Papers*, 53, 1420 (1995).

O'Donnell, H.J. and Baird, D.G.: In Situ Reinforcement of Polypropylene with Liquid Crystalline Polymers: Effect of Maleic Anhydride-Grafted Polypropylene, *Polymer*, 36, 3113-3126 (1995).

Robertson, C.G., de Souza, J.P., and Baird, D.G.: Composites Based on Fabric Prepregs Generated from In Situ Reinforced Thermoplastic Fibers, *ANTEC Tech. Papers*, 53 (1995).

Sabol, E.A. and Baird, D.G.: Morphology in Blends of a Thermotropic Liquid Crystalline Polymer and Polypropylene, *International Polymer Processing*, X, 124-136 (1995).

Sabol, E.A., Handlos, A.A., and Baird, D.G.: Composites Based on Drawn Strands of Thermotropic Liquid Crystalline Polymer Reinforced Polypropylene, *Polymer Composites*, 16, 330-344 (1995).

Smartt, L.M. and Baird, D.G.: The Role of Gate Location in the Development of Morphology and Properties of Injection Molded Liquid Crystalline Polymer/Thermoplastic Blend Composites, *ANTEC Tech. Papers*, 53, (1995).

Manuscripts Published - 1996

de Souza, J.P. and Baird, D.G.: In Situ Composites Based on Blends of a Poly(ether imide) and Thermotropic Liquid Crystalline Polymers Under Injection Molding Conditions, *Polymer*, 37, 1985-1997 (1996).

Handlos, A.A. and Baird, D.G.: Injection Molding of Microcomposites Based on Polypropylene and Thermotropic Liquid Crystalline Polymers, *International Polymer Processing*, XI, 82-93 (1996).

Handlos, A.A. and Baird, D.G.: Sheet Extrusion of Microcomposites Based on Thermotropic Liquid Crystalline Polymers and Polypropylene, Polymer Composites, 17, 73-85 (1996).

McLeod, M.A. and Baird, D.G.: Thermal Transitions Important to the Processing of Thermotropic Liquid Crystalline Polymers, 12th Polymer Processing Society Annual Meeting (Sorrento, Italy) (1996).

O'Donnell, H.J. and Baird, D.G.: The Effect of Injection Molding Conditions on the Mechanical Properties of an In Situ Composite, International Polymer Processing, XI, 257-270 (1996).

O'Donnell, H.J. and Baird, D.G.: The Effect of Injection Molding Conditions on the Mechanical Properties of an In Situ Composite, I: Polypropylene and a Liquid Crystalline Copolyester Based on Hydroxynaphthotic Acid, *Polymer Engineering and Science*, 36, 963-977 (1996).

Robertson, C.G., de Souza, J.P. and Baird, D.G.: Liquid Crystalline Polymer Systems: Technological Advances - Chapter 6: Development of In Situ Reinforced Polypropylene Fibers for Use in Formable Woven Preforms, ACS, Washington DC, 1996.

Manuscripts Published - 1997

Krishnaswamy, R.K. and Baird, D.G.: Wholly Thermoplastic Composites from Woven Preforms Based on Nylon-11 Fibers Reinforced In Situ with a Hydroxyquinone-based Liquid Crystalline Polyester, *Polymer Composites*, 17, 1-13 (1997).

McLeod, M.A. and Baird, D.G.: Injection Molding of Thermoplastics Reinforced with Pregenerated TLCP Fibrils, *ANTEC Tech. Papers*, 55 (1997).

Manuscripts Published - 1998

Gray, R.W., Baird, D.G. and Bøhn, J.H: Effects of Processing Conditions on Parts Reinforced with Short Fiber TLCPs Generated Via Fused Deposition Modeling, *ANTEC Tech. Papers*, 56 (1998).

McLeod, M.A. and Baird, D.G.: Coinjection Molding of Pregenerated Microcomposites, *ANTEC Tech. Papers*, 56 (1998).

Manuscripts Submitted or in Preparation

Gray, R.W., Baird, D.G., and Bøhn, J.H.: Effects of Processing Conditions and Prototypes Fabricated by FDM, submitted to *Rapid Prototyping Journal.*

Gray, R.W., Baird, D.G., and Bøhn, J.H.: Effects of Processing Conditions on Long Fiber Composites, submitted to *Polymer Composites.*

McLeod, M.A. and Baird, D.G.: The Influence of Processing Variables on the Mechanical Properties of Injection Molded Pregenerated Microcomposites, submitted to Composites Part B: Engineering.

McLeod, M.A. and Baird, D.G.: Injection Molding of Poly(ethylene terephthalate) Reinforced with Pregenerated Thermotropic Liquid Crystalline Polymer Microfibrils, submitted to Polymer Composites.

McLeod, M.A. and Baird, D.G.: The Crystallization Behavior of Blends of Thermotropic Liquid Crystalline Polymers, submitted to Polymer.

McLeod, M.A. and Baird, D.G.: Polymer Blends: Formulation and Performance - Chapter 32: Liquid Crystalline Polymer Blends, submitted to John Wiley and Sons.

McLeod, M.A. and Baird, D.G.: Ternary In Situ Composite Strands Containing a High Melting Thermotropic Liquid Crystalline Polymer, in preparation.

Robertson, C.G. and Baird, D.G.: Comparison of Two Methods for Generating Composite Fibers of Polypropylene and a Thermotropic Liquid Crystalline Copoly(ester-amide), accepted by *International Polymer Processing.*

D. List of Reportable Inventions

Patent Application/Invention Disclosure: "A process to generate thermoplastic fibers reinforced with TLCP's for composite applications". Cited in the 1995 Technical Progress Report.

E. List of Participating Scientific Personnel and Degrees Awarded

Post Doctoral Research Associates:

- Dr. J. Paulo de Souza
- Dr. Raj Krishnaswamy

Doctoral Candidates:

- Michael A. McLeod (Ph.D. completed on 12/97)
- Larry Michael Smartt

Masters Candidates:

- Robert W. Gray IV (Master's Thesis completed on 07/97)
- Christopher G. Robertson (Master's Thesis completed on 08/95)

Other Personnel:

- Sujan Bin Wadud